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Introduction - Dose

The issue of the radiation dose in the electromagnetic (EM) and hadronic (HAD) compartments of calorimeters has been discussed previously [1]. The purpose of this note is to connect the radiation dose, by way of the "damage profile", to the physical quantities in question which define the performance of the calorimeter system. The dose (GY $\equiv$ Gray = 100 RAD) is shown in Fig. 1 for a lead sphere geometry. The ionizing dose is roughly proportional to the particle energy striking unit area, A. We will assume that all charged particles have a p_t equal to the mean $< p_t >$. The energy of the charged particles is

$$\mathrm{E} = \mathrm{p} = \frac{\mathrm{p_t}}{\sin(\theta)} = \frac{<\mathrm{p_t}>}{\sin(\theta)}. \tag{1}$$

The charged particle flux is (where R is the radius of observation,)

$$\frac{1}{\mathrm{R}^2}\frac{\mathrm{dN_{ch}}}{\mathrm{d}\Omega} = \frac{1}{\mathrm{R}^2}\frac{\mathrm{dN_{ch}}}{\mathrm{d}\eta}\frac{\mathrm{d}\eta}{\mathrm{d}\Omega} = \frac{\mathrm{k}}{\mathrm{R}^2}\frac{\mathrm{d}\eta}{\mathrm{d}\Omega} = \frac{\mathrm{k}}{\mathrm{R}^2 2\pi \sin^2(\theta)} \tag{2}$$

and k is the roughly constant height of the rapidity plateau. Thus we find that the dose is

$$\mathrm{Dose} = \frac{\mathrm{k} < \mathrm{p_t} > \mathrm{dA}}{\sin^3(\theta)\mathrm{R}^2}. \tag{3}$$

At small angles the dose goes as $\exp(3\eta)$ as seen from the above equation and also from Fig. 1. Since the EM longitudinal shower profile has a characteristic dimension of the radiation length

X_0, while the HAD shower scale is the absorption length, it is expected that the radiation dose (energy/weight) will be less in the HAD compartment. This behaviour is seen in Fig. 1. as is the $1/R^2$ dependence. Figure 1 is calculated from the following equation [2]

$$\text{Dose rate from photons (Gy/year)} = \frac{124.}{(100\text{cm})^2 \sin^{2.93}(\theta)} \tag{4}$$

$$\text{Dose rate from hadrons (Gy/year)} = \frac{29.}{(100\text{cm})^2 \sin^{2.87}(\theta)} \tag{5}$$

The endcap occupies the region from $1.5 < \eta < 3.0$, and is approximately at a distance of 4 meters from the beam line. The dose rate for the endcap is given in Table I.

The Damage Profile

Radiation damage in the hadron compartment is caused by hadrons from "minbias" events. The relevant energies at $\eta = 3$ are roughly $<p_t>/\sin(\theta)$ or $E \leq 0.7$ GeV/sin(5.7 degrees) = 7 GeV. In order to make a model of the damage, we use 15 GeV data [3] on energy deposition. The longitudinal profile f(z), was normalized to 1 integrated over all z. A weight was defined to be, $WT(z) = 1 - gf(z)$. Typically, for $g = 1$ the minimum value of the weight was ~ 0.8. A plot of WT(z) for $g = 1$ is shown in Fig. 2. Note that each layer, except the first, is 0.7 absorption lengths thick. Thus, the hadronic shower maximum for 15 GeV incident pions occurs at a depth ~ 1.5 absorption lengths. We further assume that the damage is local, so that the response is proportional to the weight. This assumption has proved to be valid in the case of EM radiation damage [4,5,6]. For EM doses the peak damage $\overline{d}$, $WT(z) = 1 - d(z)$, appears to be roughly related to the peak dose D as

$$\overline{WT} = 1 - \overline{d} = e^{-\frac{D}{D_0}} \tag{6}$$

where the characteristic dose, D_0, for SDC standard plastics is ~ 3 Mrad. Therefore, a dose of 1 Mrad would lead to a peak damage factor of $\overline{d} = 0.28$ or $\overline{WT} = 0.72$.

Nonlinearity and Resolution

Having made a model of the induced nonuniformity of the detecting medium, one can continue and find the effect on performance of the detector. To that end data [3] from hadronic showers was weighted in each layer by WT(z) for different assumed peak damages $\overline{\mathrm{d}}$, due to radiation doses, D. Incident energies of 50, 100, 200, and 450 GeV were used. To characterize the response of the nonuniform detector, fractional induced nonlinearity and fractional induced resolution factor due to nonuniformity were examined.

The results are shown in Fig. 3a and Fig. 3b. The nonlinearity is energy independent and linearly related to the peak damage $\overline{\mathrm{d}}$. The slope is $\sim$ 6% nonlinearity for a damage of 10%. This means that one will need to monitor and calibrate the damage profile, WT(z), if peak damages of $>$ 10% are sustained in order that the hadronic energy response not be degraded.

The induced "constant term" is also roughly energy independent and linearly related to the peak damage, as seen in Fig. 3b. A peak damage of 10% leads to a contribution to hadronic resolution of $\sim$ 2%. This value is near the SDC specification of a maximum allowable constant term [7].

Summary

The main result of this study is that the hadronic performance of the calorimeter degrades significantly for peak damages $>$ 10%. One estimates, on the basis of EM studies, that this level of damage occurs for a peak dose of approximately 0.32 Mrad. This dose is delivered to a HAD calorimeter at SSC design luminosity in 10 years at η of $\sim$ 2.5.

References

[1] "Radiation Damage Testing at the SSC",SSCL-SR-1054, June 1990, ed. by W. Chinowsky and R. Thun.

[2] "Radiation Levels in Detectors at the SSC" Donald E. Groom, p18, SSCL-SR-1054, June 1990.

[3] W. K. Sakumoto *et al.* Nucl. Instr. and Meth. **A294**, 179 (1990). We have used the lab E data, private communications from W. K. Sakumoto.

[4] P. Bonamy *et al.* SDC-91-00011, Mar. 1991, SDC-91-00126, Nov. 1991.

[5] S. Funaki *et al.* SDC-91-00085, Oct. 15, 1991.

[6] L. Hu *et al.* SDC-91-00119, 1991.

[7] Letter of Intent by the Solenoidal Detector Collaboration SDC-91-00151, Nov. 20, 1991.

TABLE I.

Dose Rate			
η	θ(deg)	EM(Mrad)/(10 years)	HAD(Mrad)/(10 years)
1.5	25.16	0.095	0.022
2.0	15.41	0.376	0.083
2.5	9.39	1.57	0.34
3.0	5.70	6.73	1.43

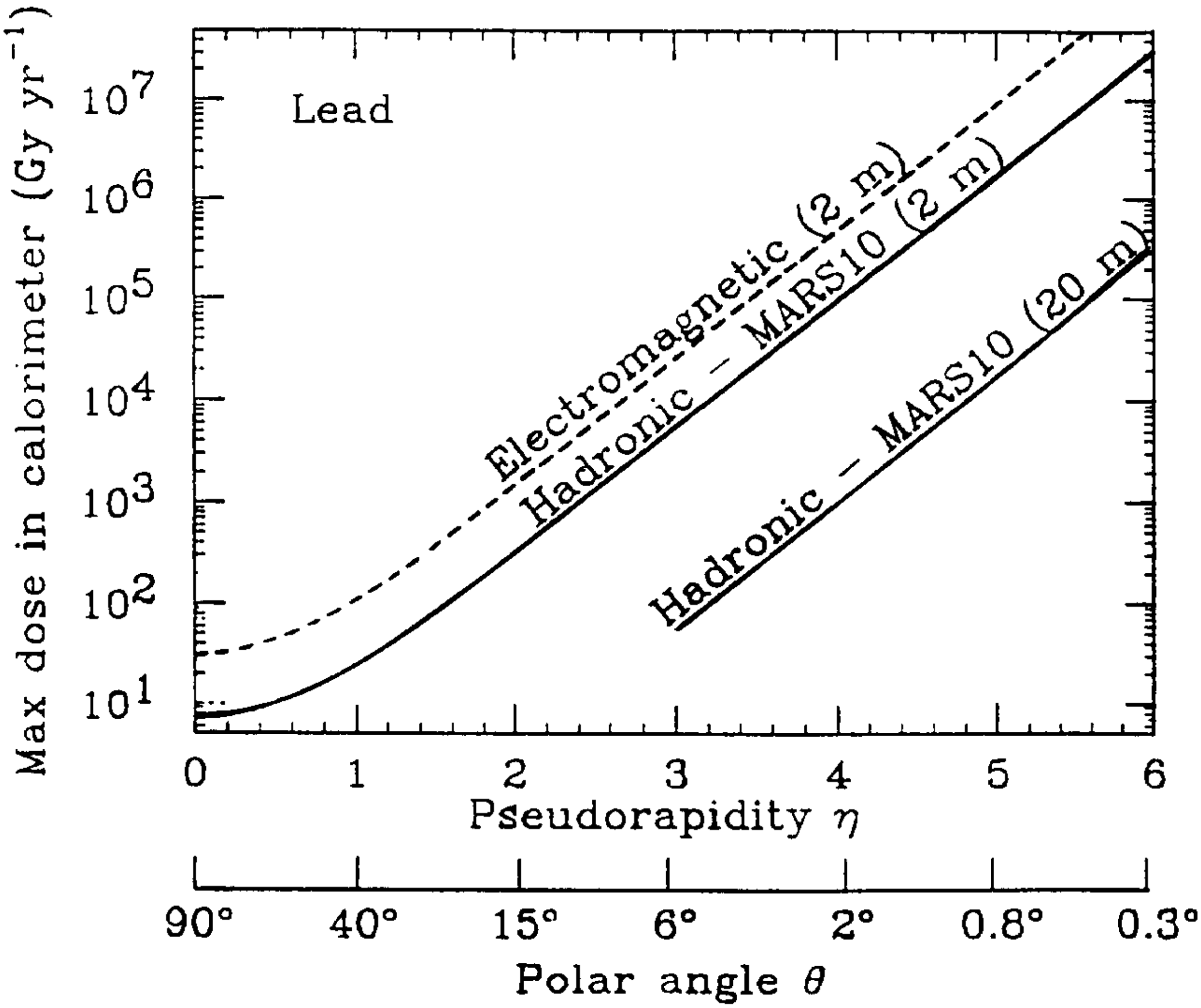

Figure 1: SSC study results (from Ref. 2) for maximum dose in a HAD shower as a function of pseudorapidity (η) for a lead sphere. The maximum electromagnetic dose in 1:1 uranium:scintillator is shown by the dashed line. Since the radiation length, nuclear interaction length, and density are nearly identical for the two materials (but not neutron flux) results may be compared directly. Note the characteristic $e^{3\eta}$ behavior. Note also the EM/HAD ratio at fixed η.

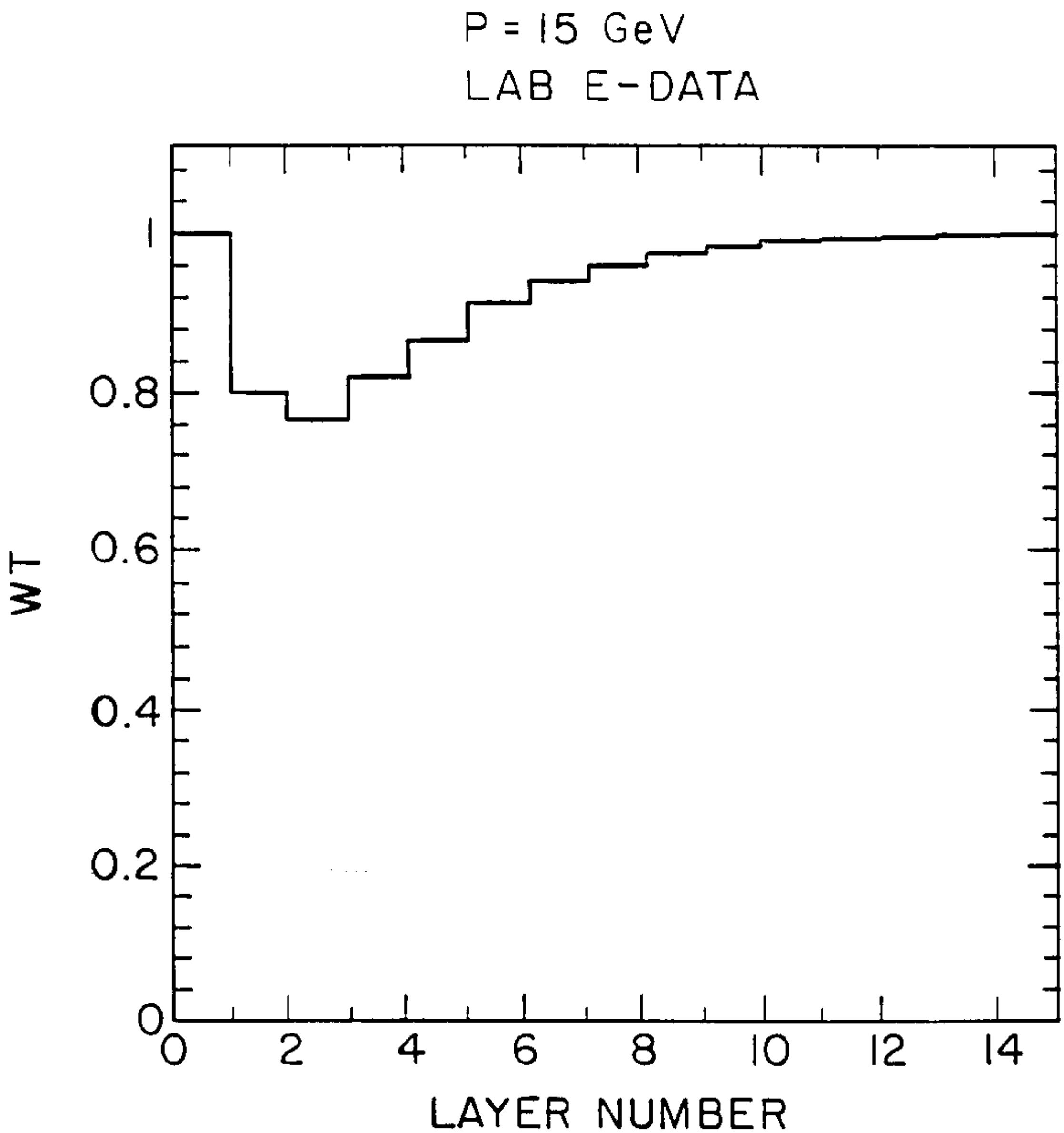

Figure 2: Weight profile in a calorimeter assuming that 15 GeV hadrons are responsible for the damage. The weight WT(z) = 1 - d(z), is plotted vs z assuming that d(z) = gf(z). The plot is for g = 1, given that the integral of f(z) is defined to be normalized to 1. A layer is $\sim$ 0.7 absorption lengths.

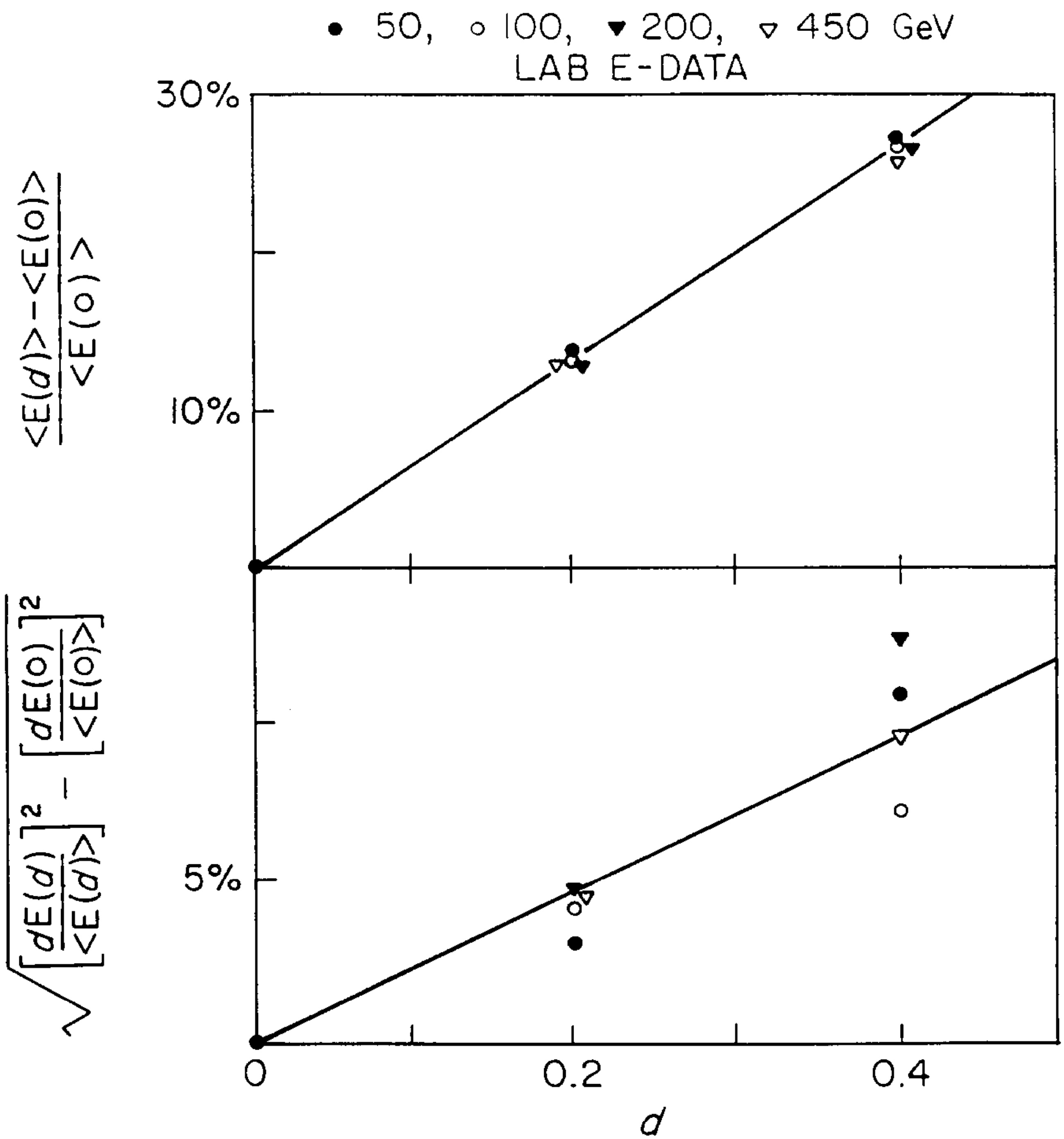

Figure 3: Mean nonlinearity and induced constant fractional energy error as a function of the peak damage $\overline{d}$ for hadrons of energy 50, •, 100 ∘, 200 ▽, and 450 ▽ GeV. Both quantities appear to be roughly energy independent and linearly dependent on the peak damage coefficient, $\overline{d}$.